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SHORT COMMUNICATION

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Delineating foraging grounds of a loggerhead turtle population through satellite tracking of juveniles

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Abstract

1. Tracking of juvenile sea turtles is a research priority to inform the protection of relevant habitats and ensure sustainable rates of recruitment into adult populations. Based on satellite tracking, mixed stock analysis, and mark–recapture studies, Drini Bay in the South Adriatic Sea, Central Mediterranean, has been confirmed as an important foraging site used by loggerhead turtles from all major rookeries in the Mediterranean subpopulation.
2. Three juvenile loggerhead turtles (*Caretta caretta*) from Drini Bay were tracked for 763, 364, and 211 days respectively. All turtles exhibited different movement patterns.
3. The two smaller turtles ranged widely beyond the bay. One of these (69.5 cm curved-carapace length; CCL) used the coldest region of the Mediterranean during the first winter of tracking where mean weekly temperatures dipped below 12°C but moved southwards to warmer waters during the second winter. In comparison, the other (66 cm CCL) individual moved south to winter in warmer waters from the outset. Both individuals returned to Drini Bay during summer, demonstrating fidelity to the study site. The third turtle, which was larger (76 cm CCL), remained in Drini Bay for the duration of tracking. These results support the findings of other mark–recapture studies at Drini Bay, which have suggested that the foraging site is being used in a transient way by immature turtles.
4. All three turtles preferentially used the shallow waters (<30 m) in the south of Drini Bay. The study demonstrates a high degree of overlap between the habitat use of the three tracked turtles and that of adult turtles tracked from nesting sites, and although based on a small sample size, contributes to a growing knowledge base regarding the wider habitat use of the Mediterranean loggerhead population.

KEYWORDS

Adriatic Sea, behaviour, *caretta*, juvenile movements, Mediterranean, MPA, satellite telemetry

1 | INTRODUCTION

A research priority for sea turtles is to identify the foraging grounds used by immature individuals, to better implement appropriate protection measures and safeguard recruitment into adult breeding populations (Jeffers & Godley, 2016; Rees et al., 2017). While it is possible to track reproductive adults from breeding grounds to foraging grounds, it is less easy to find and electronically tag juveniles in the marine environment, resulting in them being the 'underrepresented majority' (Casale, 2015; Godley et al., 2008; Heppell, 1998).

While the Mediterranean loggerhead turtle subpopulation (Wallace et al., 2011) is recovering (Casale et al., 2018), it remains highly threatened by fisheries bycatch with tens of thousands of annual mortalities conservatively estimated in the region (Casale, 2011). Such anthropogenic threats are being offset by successful nest protection efforts, therefore, while the population is considered by the IUCN (International Union for the Conservation of Nature) to be of Least Concern, its status is dependent on dedicated conservation programmes (Casale, 2015).

The Adriatic Sea is a region of high productivity and biodiversity (Coll et al., 2012). Multiple study techniques including satellite tracking, mark–recapture, mixed stock analysis, and stable isotope analysis have identified the Adriatic and north Ionian Seas as critical habitats for foraging adult and juvenile Mediterranean loggerhead turtles (Cardona et al., 2014; Casale et al., 2018; Luschi & Casale, 2014; Rees et al., 2017; Schofield et al., 2013). The largest Mediterranean loggerhead turtle rookeries are in western Greece (Casale et al., 2018). A large proportion of turtles using these nesting sites utilize foraging sites in the Adriatic and north Ionian Seas (Cardona et al., 2014; Schofield et al., 2013). Moreover, across Mediterranean nest sites from Greece, through Turkey, the Levant and North Africa, loggerhead turtles that forage in the productive Adriatic region, show high fecundity (Cardona et al., 2014), further underlining the conservation value of these foraging areas. Despite this, tracking studies to delimit conservation areas for sea turtles in the South Adriatic, particularly those including juvenile turtles, are lacking and have been identified as a research priority to inform conservation planning (Casale et al., 2018; Casale & Simone, 2017).

Juvenile loggerhead turtles undergo an oceanic development phase in oceanic waters (Walker & Parmenter, 1990). After a period of >10 years post-hatching, maturing or mature turtles generally move into neritic areas, where benthic feeding increasingly predominates over pelagic feeding (Casale et al., 2012; Laurent et al., 1998; McClellan & Read, 2007). Loggerhead turtle populations of other ocean basins show a greater propensity to retain nomadic oceanic feeding as adults (Hatase et al., 2002; Hatase, Omuta, & Tsukamoto, 2007; Hawkes et al., 2006; McClellan & Read, 2007; Rees et al., 2010), whereas nearly all adult Mediterranean loggerhead turtles tracked exhibit high fidelity to one or a small number of discrete benthic foraging sites (Schofield et al., 2013; Snape et al., 2016). Considering tracking studies of adult and juvenile loggerhead turtles in the Mediterranean, an ecological model is proposed whereby Mediterranean loggerhead turtles shift at a relatively early stage of development from pelagic oceanic to benthic neritic feeding, with a gradual reduction of home range size (Casale et al., 2012). Studies of juvenile Mediterranean loggerhead turtles indicate that they move broadly among multiple foraging sites at which they may reside for long periods and show high fidelity (Casale, Affronte, et al., 2012; Casale, Broderick, et al., 2012; Luschi & Casale, 2014; Schofield et al., 2013).

Both adult and juvenile loggerhead turtles may make latitudinal movements to forage and escape extreme temperatures (Hawkes et al., 2011; Mansfield, Saba, Keinath, & Musick, 2009; Zbinden et al., 2011), whereas others may move to deeper waters and/or become dormant during the coldest months, diving for up to 10 hours (longer than any other air breathing marine vertebrate), with associated reduced metabolism (Broderick, Coyne, Fuller, Glen, & Godley, 2007; Hochscheid, Bentivegna, Bradai, & Hays, 2007).

White, Boura, and Venizelos (2013), experienced low interannual recapture rates among hundreds of tagged turtles caught in pound nets in Drini Bay, Albania in the south Adriatic Sea, concluding that this foraging hotspot is used in a transient way by hundreds of sub-adult and adult turtles. Low recapture rates of similar size classes were reported at a foraging hotspot south of here in Amvrakikos Gulf, in the north Ionian Sea (Rees et al., 2013). Satellite tracking showed turtles to be predominantly resident, with some transience among turtles including migration to nesting sites (Rees et al., 2013; Rees et al., 2017). Both of these foraging hotspots have recently been found through satellite telemetry, mark–recapture, and mixed stock analysis, to host loggerhead turtles originating predominantly at Greek rookeries, and from other significant rookeries including Turkey and Cyprus (Rees et al., 2017; Schofield et al., 2013; Yilmaz, Turkozan, Bardakci, White, & Kararaj, 2012), across the range of this population.

In Drini Bay, Albania, loggerhead turtles are routinely trapped and released unharmed as non-target catch in pound net fisheries. Partnering with these fisheries has allowed characterization of turtle demographics (including life stages found and source populations) through aforementioned studies (Rees et al., 2017; White et al., 2013; Yilmaz et al., 2012). Here we report on the first satellite tracking of juveniles from this foraging site. Our aims were: (a) to delineate conservation areas to protect turtles using this site from anthropogenic threats; (b) to determine the degree of fidelity of juvenile turtles to this foraging site; and (c) to understand connectivity between the study site and other important habitats.

2 | METHODS

On 12 September, 2009, using a limited budget raised by the nonprofit conservation organization MEDASSET, three turtles were selected from ongoing mark–recapture studies in pound net fisheries (White et al., 2013) and taken ashore for satellite transmitter attachment. Carapace length (CCL; Casale, Freggi, Basso, & Argano, 2005) was measured to infer body size (Table 1) and turtles were chosen from the most commonly encountered size classes (41% are 60–70 cm and 27% are 70–80 cm (n = 387; White et al., 2013). The

TABLE 1 Measurements, tracking durations, number of filtered locations, home range estimates, and depth at location statistics (for depth data source see Coyne & Godley, 2005) for the three turtles tracked during this study. CCL = curved carapace length. All deployments were made on 12 September 2009

Turtle ID	CCL (cm)	Final tracking day	Tracking duration (days)	Oceanic habitat use (days)	Filtered locations	Home range estimate (km^2) 90%	50%	20%	Depth (m) median (IQR)
1	69.5	15/10/2011	763	61	1,162	98,121	16,093	2,368	48.5 (7.4–135.4)
2	66	11/09/2010	364	4	349	10,890	1,156	300	28.2 (11.4–41.0)
3	76	11/04/2010	211	0	159	302	80	19	19.4 (10.7–29.9)

method of Casale et al. (2014), who used the rookery-weighted mean CCL of nesting Mediterranean loggerhead females to assume that turtles below 79.7 cm were juveniles, was used, so all three turtles were considered juveniles (Table 1). Satellite transmitters (SPOT tags, Wildlife Computers, Redmond, WA, USA) were attached to the second vertebral scute of the carapace using epoxy resin and the turtles were released from the shore at nearby Patok (41°37′25″N, 19°34′39″E). Transmitters were programmed to transmit with a repetition rate of 45 seconds and only when a saltwater switch was broken during surfacing.

Argos location data were handled using Satellite Tracking Analysis Tool (STAT), which also provides estimates of sea surface temperature, speed of travel, and sea depth at filtered locations (for details see: Coyne & Godley, 2005). Location data were filtered according to Argos location class (accuracy estimates for locations provided by the Argos system) according to the method used by Snape et al. (2018), whereby location class Z and any requiring swimming speeds of >5 km h^{-1} are removed. To limit spatial inaccuracy and bias resulting from autocorrelation, location data were also filtered to a single daily location following Witt et al. (2010) with descending

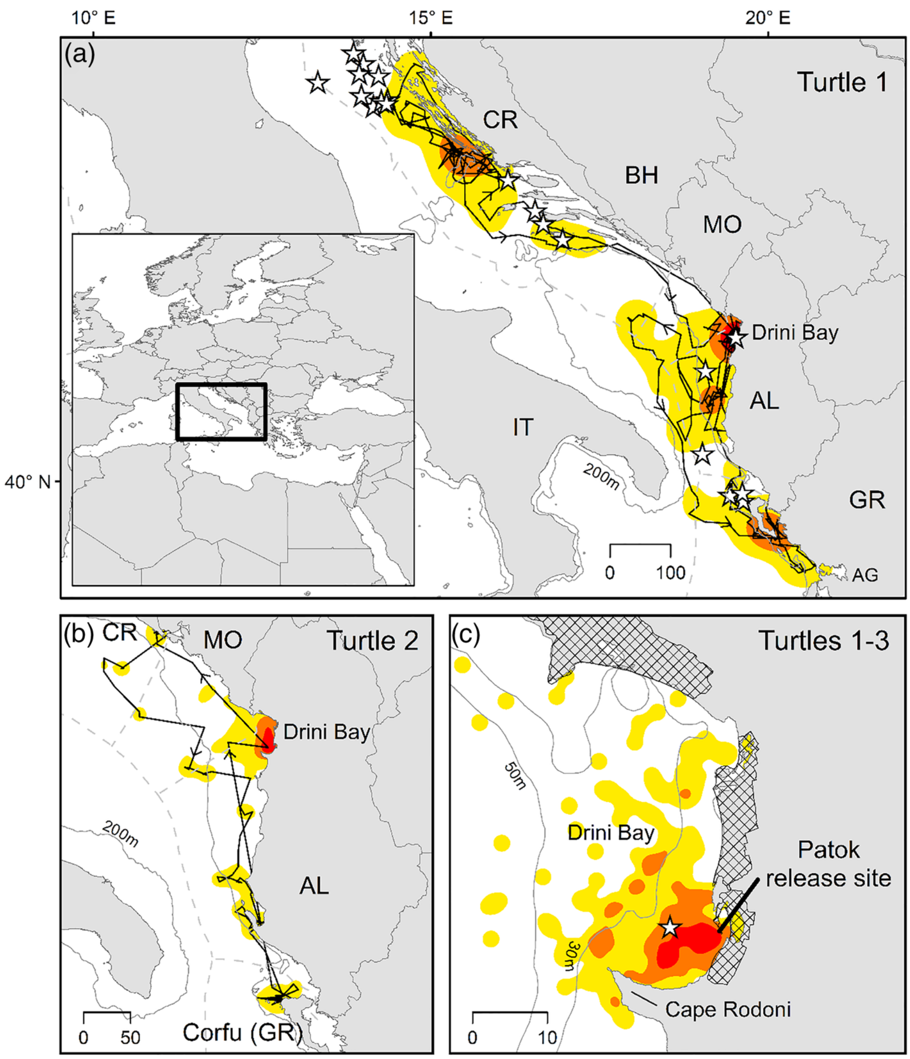

FIGURE 1 Habitat utilization density estimates and movement patterns (black lines with arrows) for (a) turtle 1, (b) turtle 2, and (c) for all three turtles during their residence in Drini Bay. Tracking start and end locations were all within Drini Bay. Hatched sites indicate coastal protected areas. Ninety, 50, and 20% utilization densities are represented by yellow, orange, and red tones, respectively. Dashed grey line indicates Exclusive Economic Zone and solid grey bathymetric contours are labelled with their respective depth. White stars show estimated central location (for centring method see Schofield et al. [2013]) of foraging sites used by 20 breeding adult turtles tracked from Zakynthos Island, Greece (Schofield et al., 2013; Zbinden et al., 2011). Scale bar shows km. CR: Croatia, BH: Bosnia and Herzegovina, MO: Montenegro, AL: Albania, GR: Greece, IT: Italy, AG: Amvrakikos Gulf

preference LC (Location Class) 3, 2, 1, A, B, 0. If two or more locations of the same preferred LC remained within a given day, the median of these locations was used (Snape et al., 2018). Habitat utilization distributions (UDs) of 90% and 50% were calculated to determine total and core habitat use respectively (Börger et al., 2006) whilst 20% UDs were used to determine areas of intense utilization (Casale, Broderick, et al., 2012; Snape et al., 2018). Using filtered tracking data, the number of days that each turtle spent in oceanic habitats was calculated by summing periods where more than one consecutive location occurred in depths >200 m. To summarize cumulative habitat use across the three turtles, within Drini Bay, data were pooled across individuals and analysed as above, while 50% habitat UDs of individual turtles were also calculated separately to show individual variation and degree overlap.

The central locations (median location coordinates) of foraging sites used by 20 adult turtles tracked from Zakynthos, a major nesting site for the population (for attachment details see Schofield et al., 2013, Zbinden et al., 2011), are provided and compared with the habitat use of the three juvenile study turtles (Figure 1a-c, Figure 2b).

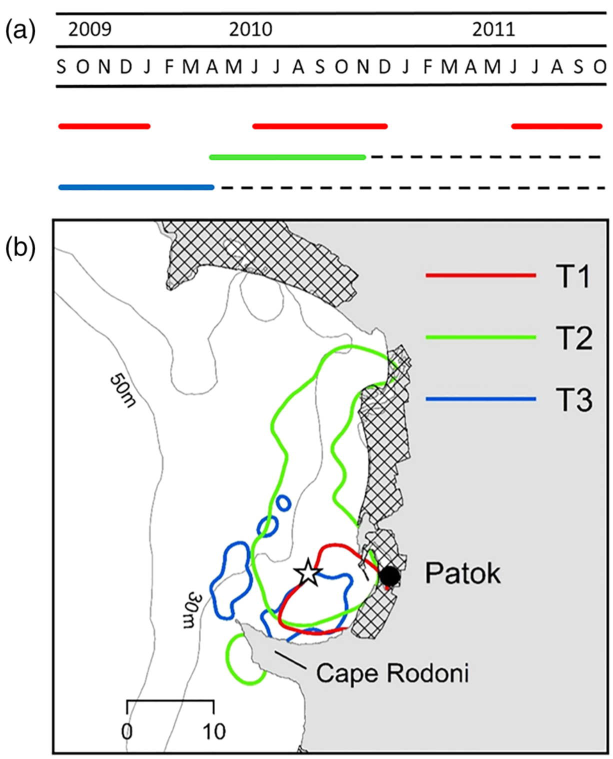

FIGURE 2 Temporal (a) and spatial (b) distributions (50% utilization density) of turtles 1 to 3 in Drini Bay. Each colour represents turtles 1–3 according to the insert legend. Horizontal lines against month of year represent months during which turtles were resident in Drini Bay. Dotted lines denote periods proceeding the last location received, when the location of turtles was not known. White star shows estimated central location of foraging site used by one of 20 breeding adult turtles tracked from Zakynthos Island, Greece (Schofield et al., 2013; Zbinden et al., 2011). Hatched terrestrial sites indicate coastal protected areas. Scale bar shows km

3 | RESULTS

The three turtles exhibited very different movement patterns. Turtle 1 which was tracked for 2 years, moved to higher, colder, latitudes (off Croatia) in the first winter where mean weekly temperatures of <12°C were experienced (Figure 1a). Turtle 1 returned to Drini Bay during the following summer and migrated to lower, warmer, latitudes (off the Epirus coast of Greece and south coast of Corfu, north Ionian Sea) in the second winter (Figure 1a). Turtle 1 used much broader foraging areas than the other two turtles, did not forage at any discrete location and spent periods (max: 33 days) roaming in oceanic waters (Figure 1a, Table 1). Turtle 2, which was tracked for 1 year, immediately migrated to overwinter at a discrete foraging site at a lower latitude in the warmer north Ionian Sea (north coast of Corfu) and briefly visited two other sites (southern Croatia and southern Albania, Adriatic Sea; Figure 1b). Turtle 3 was tracked for 7 months and remained in Drini Bay for the duration of the study.

Drini Bay (Figure 1c) was occupied by at least one of the three turtles for the first full year of the study (Figure 2a). Although two turtles moved out of Drini Bay to use other areas of the Adriatic and North Ionian Seas during cold months, both showed a high degree of fidelity (in particular turtle 1) to the release site (Figure 1c, 2b), returning to Drini Bay for the summer. Within Drini Bay, all three turtles predominantly frequented the southern quarter of the bay, with overlapping habitat use in waters of less than 30 m depth (Figure 1c, Figure 2b). A winter foraging site in Drini Bay of one adult turtle overlapped foraging sites of all three juvenile turtles (Figure 1c, Figure 2). All three study turtles used habitats that were also frequented by adult females tracked after nesting at Zakynthos nesting beach (Figure 1a-c).

4 | DISCUSSION

Tracking the movement patterns of multiple individuals from a discrete foraging site provides valuable information towards integrating the protection of loggerhead turtles in Drini Bay. Mitigation of human threats at this site is particularly important, since it supports foraging turtles originating from several of the largest rookeries of this population, potentially having wide-reaching benefits (Rees et al., 2017; Yilmaz et al., 2012). The data thus contribute toward a research priority recently raised for this population (Casale et al., 2018).

Tracking has shown that loggerhead turtles use Drini Bay as a seasonal summer foraging site (current study) and as an overwintering site (Schofield et al., 2013, current study). Such seasonal migrations of some loggerheads foraging in the cold north Adriatic, to warmer more southerly foraging sites during winter, has been demonstrated before (Casale, Affronte, et al., 2012; Schofield et al., 2013; Zbinden et al., 2011). Seasonal migrations have been shown for other loggerhead populations using cold northerly waters (e.g. Hawkes, Broderick, Coyne, Godfrey, & Godley, 2007; McClellan & Read, 2007). Seasonal movements are to be expected as sea surface temperatures in the north Adriatic are the coldest in the Mediterranean (Hochscheid et al., 2007), and for long-term residency these temperatures are below the preferred lower temperature limits for this species (13.3°C; Coles & Musick, 2000). However, a juvenile migrated from Drini Bay into the north Adriatic just as temperatures were reaching their lowest, with weekly mean sea surface temperature experienced in March below 12°C. The turtle switched its behaviour during the second year of tracking, possibly because the voluntary reduction of metabolism associated with occupying such cold northern waters, was not worth any positive nutritive benefits in that region. A juvenile loggerhead turtle tracked by Casale, Affronte, et al. (2012), experienced winter temperatures of 10°C in the northernmost point of the Adriatic, thus, some juvenile Mediterranean loggerheads may often overwinter in these cold-water north Adriatic habitats. The combination of seasonal oceanic movements and periods of feeding at discrete benthic habitats, with strong remigration fidelity, shown by turtles 1 and 2, were aligned to those of other juvenile loggerheads tracked in the region (Casale, Affronte, et al., 2012; Luschi & Casale, 2014). In particular, juvenile turtles tracked off the south Adriatic coast of Italy showed a combination of benthic feeding at discrete sites, seasonal wandering movements, and high fidelity to coastal benthic feeding sites (Casale & Simone, 2017). The behaviour of turtle 3, the largest study turtle, was more like the majority of tracked adults, which occupy smaller, discrete neritic foraging sites, to which high fidelity is shown between migrations to nesting sites (Luschi & Casale, 2014). Although assumed a juvenile (Casale et al., 2014), this turtle may have been approaching adulthood, as it was within the range of adult sizes tracked from Greek rookeries by Schofield et al. (2013). The behaviour of turtle 2 seemed to be intermediate, with some opportunistic behaviour, briefly stopping between two established discreet foraging sites at Drini Bay and off northern Corfu. The movement patterns and habitat UDs of the turtles tracked here therefore broadly fit the model proposed by Casale, Affronte, et al. (2012) for the Mediterranean loggerhead turtle population, where the progression from feeding in the water column, to benthic neritic feeding occurs relatively early in development.

A caveat of this study is its very limited sample size, a reflection of the significant costs of satellite telemetry and the limited fiscal resources available to the project. However, tracking of three turtles from the same foraging site, with a high degree of overlap and for long tracking periods, is novel and provides information relevant to loggerhead turtle conservation in Albania, contributing to existing information for Drini Bay and for important areas of the Adriatic and borth Ionian Seas. Albania has a network of terrestrial protected areas, including the coastline of Drini Bay (Figure 1c, 2b), which, by law, should encompass adjacent marine habitats as MPAs, but no marine habitats have yet been delineated (RAC/SPA & IUCN-Med, 2014). Although the sample size of the current study is limiting, the south of Drini Bay supports hundreds of loggerhead turtles annually (White et al., 2013), therefore the foraging areas delimited by this study would make a useful candidate area for inclusion in an MPA. However, further tracking using capture methods not biased to fisheries, or use of novel methods such as aerial surveys (Grey et al., 2019) to delimit the distribution of turtles in the area with greater confidence, are recommended.

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